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Degree: Master of Science

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"Grass is the forgiveness of nature; her constant benediction. Sown by the winds, by wandering birds, propagated by the subtle horticulture of the elements which are its ministers and servants, it softens the rude outline of the world. Its tenacious fibers hold the earth in place, and prevent its soluble components from washing into the wasting sea. It bears no blazonry or bloom to charm the senses with fragrance of splendor, but its homely hue is more enchanting than the lily or the rose. It yields no fruit in earth or air, and yet should its harvest fail for a single year, famine would depopulate the world."

Senator John James Ingall, 1872

University of Alberta

Grazing Effects On Runoff And Erosion In Annual And Perennial Pastures In The Parkland Ecoregion Of Alberta

by

Suzanne Irene Gill

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Science

in

Water and Land Resources

Department of Renewable Resources

Edmonton, Alberta

Spring 1997

University of Alberta

Faculty of Graduate Studies and Research

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled Grazing Effects on Runoff and Erosion in Annual and Perennial Pastures in the Parkland Ecoregion of Alberta submitted by Suzanne Irene Gill in partial fulfillment of the requirements for the degree of Master of Science in Water and Land Resources.

DEDICATION

This thesis is dedicated to Dorothy and Donald Swenson, who showed me that the land can be coaxed back from the brink of annihilation and who inspired my return to school by their triumph over soil degradation and their success in returning their land to productivity.

ABSTRACT

A study was conducted in the Alberta parkland at Lacombe to assess erosion on smooth bromegrass, meadow bromegrass, triticale and triticale/barley forage treatments under heavy, medium and light grazing intensities. Objectives were to quantify select vegetation characteristics and total runoff and sediment yields from snowmelt and rainfall events on forage and grazing treatments and to measure relationships between select vegetation characteristics and runoff and sediment yield for each forage treatment. Total runoff and sediment yields were low and total runoff was generally greater for snowmelt than rainfall. Bare ground, leaf area index and post-grazing biomass decreased with increasing grazing intensity. Bare ground was significantly greater in annuals than perennials. Black Chernozemic soils of this region have a good infiltration capacity and runoff occurs only during spring snowmelt and larger precipitation events. The risk of water erosion is low on this site with proper grazing management.

ACKNOWLEDGEMENTS

My thanks are extended to CAESA for the funding for this research and to the Lacombe Agriculture and Agri-Food Canada Research Centre for extensive technical support and provision of a research site. Foremost on my list of people to thank for their support is my supervisor, Anne Naeth. Her compassion and caring made my university experience so much richer. The remainder of my committee, David Chanasyk, Robert Hardin and Vern Baron, were a pleasure to work with, both for their expertise and their outlook on life. My husband continued working diligently to “keep me in the manner to which I was accustomed” while in school. I will forever appreciate the support and encouragement he gave me in my return to the academic sphere. Many wonderful people at the University of Alberta added greater academic and social richness to my time there; my long term office mates Dana Bush and Debra Brown, my “Lacombe study buddy” Dennis Twerdoff, Kelly Ostermann, Robin Lagroix-MacLean, Andy Hammermeister, Bill Pelech, Ted Harms and so many others. Finally, I wish to thank a certain orange feline who kept me warm and comfortable and witnessed the creation of this thesis from the vantage point of my lap!

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CHAPTER 1

INTRODUCTION

1.1 Background

There are approximately 8.1 million ha of pasture and rangeland within the province of Alberta (Statistics Canada 1991a). These pastures are depended upon heavily by the Alberta cattle industry which annually adds $1.5 billion to the provincial economy (Statistics Canada 1991b). Fluctuating cattle prices from year to year result in fluctuating cattle numbers and fluctuating demand for pasture on a yearly basis. Flexibility in the number of hectares in pasture is therefore an important competitive tool for Alberta beef producers.

The use of perennial pasture to meet soil conservation and economic goals is common in the Parkland Ecoregion. Perennial pasture is used in rotation with annual crops or to improve land which is marginal for topographical or soil quality reasons. It is also used as a complement to native range to extend the grazing season.

With the demise of Crow Rate payments, it is conceivable that more feed grains will stay on the Prairies, causing an increase in cattle numbers and a corresponding increased demand for pasture (Fairbairn 1995). Perennial pasture may assuage much of this demand, but annual pastures have an important role to play in the provision of grazing later in the growing season when perennial pasture cannot keep pace with grazing demand.

1.2 The Parkland Ecoregion

The Parkland Ecoregion is approximately 52,148 km^2, 7.9% of the land area of the province (Strong and Leggat 1992), bounded on the north by boreal forests and on the south by grasslands. The natural vegetation consists of a mixture of grassland and deciduous forest plant communities. In the southern, drier portion of the Aspen Parkland, the grassland component dominates and trembling aspen (*Populus tremuloides* Mitchx.) comprises approximately 15% of the cover. In the grasslands, rough fescue (*Festuca hallii* Torr.), bluebunch fescue (*Festuca idahoensis* Elmer), June grass (*Koeleria macrantha* (Ledeb.) J.A. Schultes f.), needle grasses (*Stipa columbiana* Macoun, *Stipa comata* Trin.

& Rupr., *Stipa curtiseta* (A.S. Hitchc.) Barkworth, *Stipa spartea* Trin., *Stipa viridula* Trin.), old man's whiskers (*Geum triflorum* Pursh), sticky purple geranium (*Geranium viscosissimum* Fisch. & Mey.) and northern bedstraw (*Galium boreale* L.) are the dominant species. The northern and western portions of the ecoregion are moister and are dominated by trembling aspen clones with patches of grassland. A diverse understory is present under aspen stands where soil moisture and humidity are sufficient. Here species such as veiny meadow rue (*Thalictrum venulosum* Trel.), bedstraw (*Galium boreale* L., *Galium labradoricum* Wieg., *Galium trifidum* L., *Galium triflorum* Michx.), wild strawberry (*Fragaria virginiana* Duchesne), rose (*Rosa acicularis* Lindl., *Rosa woodsii* Lindl.), tall larkspur (*Delphinium glaucum* S. Wats.), violet (*Viola adunca* J.E. Smith, *Viola canadensis* L., *Viola macloskeyi* Lloyd, *Viola nephrophylla* Greene, *Viola palustris* L., *Viola renifolia* A. Gray), saskatoon (*Amelanchier alnifolia* Nutt.), willow (*Salix bebbiana* Sarg., *Salix candida* Fluegge *ex* Willd., *Salix discolor* Muhl., *Salix exigua* Nutt., *Salix lutea* Nutt., *Salix petiolaris* J.E. Smith) and fireweed (*Epilobium angustifolium* L.) are present (Moss 1983, Strong and Leggat 1992). However, almost the entire ecoregion is comprised of agricultural land. The presence or absence of aspen currently depends much more on human intervention than on climatic influence. In a similar way, very little native prairie remains in the area, with most land being broken and seeded to agronomic species.

Much of the topography in the Aspen Parkland Ecoregion consists of rolling, gently sloping (less than 5%) hills and the majority of soils in the area are Orthic Black Chernozems with a high organic matter content in the A horizon. These highly productive soils formed beneath grassland. Dark Gray Chernozems can be found where prolonged aspen domination has eluviated the soil (Agriculture Canada Expert Committee on Soil Survey 1987, Strong and Leggat 1992).

The climate of the ecoregion is subhumid to humid continental, with a mean annual precipitation of 447.5 mm (de St. Remy 1992). Approximately 78% of this precipitation falls as rain (Kerr et al. 1993). Snowfall varies greatly with terrain, elevation and latitude, averaging 53 cm annually. The monthly average potential evapotranspiration is approximately 50 mm. The frost-free period generally exceeds 90 days and the mean annual temperature is 3.3 ^{o}C. January mean temperature is -8.7 ^{o}C while July mean temperature is 14.4 ^{o}C. The mean growing degree days for the ecoregion is 1257.

1.3 Parkland Forage Types And Their Management

Of the 1.7 million ha of improved pasture within Alberta, 700,000 ha are within the Parkland Ecoregion (Statistics Canada 1991b). Annual as well as perennial improved pastures are currently found within this Ecoregion.

In most perennial pastures in the area, bromegrass (*Bromus inermis* Leyss. and *Bromus riparius* Rehm.), timothy (*Phleum pratense* L.) and alfalfa (*Medicago sativa* L.) are the main components of the mix. Although Kentucky bluegrass (*Poa pratensis* L.) is rarely included in pasture seed mixes intended for cattle, it often invades and is a major component of established pastures in the area (Baron 1995). These pastures are most commonly seeded in the spring of the year in which they are grazed, often with an annual cover crop such as oats (*Avena sativa* L.), canola (*Brassica napus* L.) or barley (*Hordeum vulgare* L.). In the year of emergence, they are cut for hay or grazed late in the season. In an average year these forages tend to have completed 60% or more of their growth by 1 July (Baron et al. 1993). The number of years the perennial forage stand can be maintained depends on its continued productivity and the economic viability of replacing it with other crops. Perennial pasture commonly stays in production from four to fifteen years (Baron 1995).

Perennial pastures used for hay are most often harvested in mid-July and again in late August or early September. If used for grazing, several different use patterns are possible. Pasture may be continuously grazed during the entire or a portion of the growing season. In contrast, rotational grazing reduces the sward to a target height, at which time the cattle are removed and the sward is allowed to recover before cattle are reintroduced and the process is repeated.

The most common species used for annual pasture in the Parkland is oats (Baron 1995). Barley, fall rye (*Secale cereale* L.) and triticale (*X Triticosecale* Whittmack) are also grown. These pastures are row-planted in the spring and grazed late into the fall. The residue (live and dead standing and fallen plant material remaining after grazing) is left in place until the following spring, at which time the land is cultivated and replanted. Because annual pastures produce more biomass later in the season than perennial pastures, they provide late season grazing which relieves the grazing pressure on, and prevents overgrazing of, perennial pastures.

1.4 Water Erosion

The degree to which erosion occurs is governed by erosivity and erodibility. Erosivity is a measure of the energy available within precipitation and erodibility is the measure of the soil's resistance to erosion (Mitchell and Bubenzer 1980). The two major agents active in soil erosion by water are falling raindrops and flowing water. In both cases, water is acting under the force of gravity. As gravity acts on water within a system, the energy contained in that water is transferred to soil particles to cause erosion.

Velocity and mass determine a raindrop's erosive power with the terminal velocity of a raindrop being determined by air friction acting on the raindrop's mass. Raindrops in the presence of wind accelerate because the actual wind force adds a horizontal velocity component to the raindrop and air moving horizontally away from the drop reduces the air resistance, encouraging the drop to accelerate downwards (Troeh et al. 1980). Upon impacting the ground surface, raindrops release energy and aggregates and clods are broken into smaller aggregates and individual particles (detaching capacity of raindrops), soil aggregates and individual particles are moved to new locations as water splashes back up into the air (transporting capacity of rainfall) and the surface of the soil is compacted and puddled (Kirkby 1980, Troeh et al. 1980).

Surface water flow occurs when rain is falling at a rate greater than the maximum infiltration rate possible in that specific kind of soil. The kinetic energy of running water increases with velocity and quantity in the same way that a raindrop's kinetic energy increases with mass and velocity (Troeh et al. 1980). The erosive power contained in a particular body of flowing water is influenced by the characteristics of that body of water (depth of flow, transported materials, turbulence) and the characteristics of the land over which the water flows (surface condition, slope gradient, slope length, slope shape, slope aspect) (Duley and Ackerman 1934, Baver 1939, Troeh et al. 1980).

1.5 Forage Characteristics And Erosion Potential

Perennial forages are traditionally associated with soil conservation (Browning 1973, Van Doren and Triplett 1982). Perennial pasture provides year-round surface cover, minimizing raindrop impact and preventing soil aggregate breakdown. Surface litter accumulates across years which helps

curtail overland flow. This is especially important during spring snowmelt and during times of intense precipitation and/or high antecedent soil water.

The root systems of perennial forages tend to be more extensive than those of annual forages (Allison 1973, Browning 1973). The deep diffuse rooting systems associated with perennial forages such as smooth bromegrass (Casler and Carlson 1995) add nitrogen and organic matter to the soil, physically bind soil particles into aggregates and provide substrate for microbial polysaccharides which also bind soil particles into stable aggregates (Tisdall and Oades 1979, Kobayashi and Yamane 1981, Dormaar and Foster 1990, Chenu and Guerif 1991).

When annual forage pastures are cultivated and a new crop is planted in spring, the soil surface is bare and loose during a time when rainfall events of significant intensity and duration commonly occur (Alberta Agriculture 1991). Lessening of organic matter levels and decreased aggregate stability are exacerbated by yearly cultivation. Cultivation physically breaks apart aggregates held together by root pieces and increases the rate of microbial breakdown of organic matter. When the crop emerges, the row pattern of the crop may exacerbate rill erosion through channelling of water along rows. Conservation tillage practices (Mannering and Meyer 1963) which increase surface residues and contour planting across slopes (Troeh et al. 1980) can minimize erosion under these circumstances.

1.6 Grazing Regime And Soil Erosion

The time of year grazing occurs, the time of rest between grazings and the amount of biomass removed at each grazing affect the ability of the plant to regrow, produce ground cover and litter (Stoddart et al. 1975, Naeth et al. 1991a) and protect against soil erosion (Packer 1953, Johnston 1962). Early season grazing can weaken a plant by preventing it from developing sufficient biomass to replenish root systems depleted by overwintering (Stoddart et al. 1975). The time of rest between grazings and the amount of biomass removed with each grazing also affect the plant's ability to replenish carbohydrate stores (Matches 1992).

Increased grazing pressure results in less litter accumulation (Naeth et al. 1991a). Surface litter protects the soil surface from raindrop impact, provides cushioning against hoof impact and improves aggregation through addition of

organic matter to the soil. A thick litter layer also creates an increased coefficient of roughness, slowing down surface flow, causing sediments to drop out and increasing infiltration (Besler 1987).

The presence of surface litter is critical at snowmelt and during intense precipitation events. Snowmelt is a time of great erosion risk because the surface soil layer may be thawed while deeper soil layers are still frozen. This creates saturated conditions at the soil surface and increases runoff and erosion potential (Chanasyk and Woytowich 1987). Intense precipitation events can exceed infiltration capacity and result in runoff. The ability of a thick litter layer to lower antecedent soil water and increase soil infiltration capacity (Naeth 1991b) may counteract the cumulative effect of closely spaced precipitation events.

The absence or reduction of a litter layer may lead to increased compaction and runoff in some soils (Packer 1953, Rauzi and Hanson 1966). Moist soils or soils with a high clay content are more susceptible to compaction (Orr 1960, Gifford et al. 1977). In a moist soil, particle movement is enhanced by lubrication, facilitating particle shift and a decrease in pore space (Troeh et al. 1980). Clay particles align horizontally when compacted, forming a dense and impermeable surface crust.

At high grazing intensity, poor regrowth may manifest as an increase in bare ground. With an increase in bare ground comes an increase in susceptibility to raindrop impact and aggregate breakdown (Duley and Kelly 1939, Kincaid and Williams 1966). As aggregates break down, small soil particles may be washed down into soil macro- and micro-pores, effectively preventing infiltration and causing increased overland flow (Troeh et al. 1980).

1.7 Hypotheses And Objectives

Little is known about the effect of annual pastures on soil quality in the Parkland Ecoregion. Increased use of annual pastures could lead to soil degradation if effects are unrecognized. Producers will benefit from information on the soil erosion impact of both annual and perennial forages. To achieve productive use without compromising the soil resource, producers require baseline data on the effect of different grazing intensities on various pasture forages. This, in conjunction with soil conservation information regarding annual vs. perennial forages, will aid producers in making informed pasture

management decisions to ensure conservation of the soil resource into the future.

1.7.1 Objectives

1. To quantify runoff and sediment yield under four forage types (smooth bromegrass, meadow bromegrass, a barley/triticale mix and triticale) and three grazing intensities (heavy, medium and light) during spring snowmelt and precipitation events.
2. To determine whether runoff and sediment yield are affected by spring or fall litter biomass, early or late season post-grazing forage biomass, bare ground and leaf area index.

1.7.2 Hypotheses

1. Greater runoff and sediment yield may occur in annual pastures compared to perennial pastures due to differences in ability to generate ground cover. Annual pastures may generate more runoff and sediment due to yearly cultivation prior to seeding, non-permanent root systems, later establishment, lack of permanent litter cover and row planting pattern.
2. Attributes of individual forage types affect runoff and sediment yield. Based on these attributes, it is anticipated that smooth bromegrass will have the greatest erosion reducing potential, meadow bromegrass the second most, triticale the third most and barley the least.
3. Rainfall runoff and sediment depend on ground cover and litter, and will be greatest in heavy grazing treatments, intermediate in medium grazing treatments and least in light grazing treatments. Because heavy grazing involves early grazing, the least amount of rest between grazings and the most biomass removal, it should produce the least ground cover and litter. Light grazing involves late grazing, the greatest amount of rest between grazings and the least biomass removal and should produce the most ground cover and litter. Medium grazing represents the intermediate situation.
4. The time of year will interact with forage type and grazing regime, affecting runoff and sediment yield. The amount of litter will differ among treatments

but in all cases will be greatest in fall and least in spring after winter breakdown and cultivating (in annual forages).

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CHAPTER 2

GRAZING EFFECTS ON VEGETATION PARAMETERS OF ANNUAL AND PERENNIAL PASTURES IN THE ALBERTA PARKLAND

2.1 Introduction

The amount of live vegetation and litter in a pasture is a function of growth, senescence, harvest and decomposition (Coleman 1992). Grazing affects plant characteristics primarily via biomass and litter removal. Standing and fallen litter biomass, total biomass and vegetation ground cover generally decrease while amount of bare ground generally increases with increased grazing intensity (Packer 1953, Naeth et al. 1991).

The frequency and intensity of grazing and trampling change the persistence, productivity and botanical composition of the sward and the regrowth rate of plants following grazing (Matches 1992). Watkin and Clements (1978) suggested defoliation is the most important influence of grazing on pasture because carbohydrate storage, tiller development and leaf and root growth are all affected. Severity of defoliation affects regrowth via its effect on a plant's stored energy for that regrowth (Booysen and Nelson 1975). Vegetation trampling damage by sheep (Edmond 1963, 1966) and cattle (Edmond 1970, Bryant et al. 1972), separate from defoliation, reduces pasture yield. Damage increases with trampling intensity and is generally higher when soil is wet. Damage to roots, displacement of plants and burial in mud were observed under wet soil conditions in a study by Edmond (1963).

Plant species vary in their response to grazing. Plant types vary in architecture, nutrients and tissue availability, all of which influence the degree to which they are grazed (Coleman 1992). Some species develop a prostrate growth habit under grazing, making complete tiller removal less likely than in plants with upright growth (Matches 1992). The ability to reproduce via stolons and rhizomes enable some species to avoid damage to sites of regrowth and to reproduce under heavy grazing and trampling. Grass species which elevate apical meristems with vegetative tillers or which produce a high proportion of reproductive tillers are least tolerant of grazing (Briske 1986). Species which do not have these characteristics can generally be grazed more often without reducing herbage production.

Perennial and annual pasture grasses produce potentially different levels of litter, ground cover and biomass. Perennials accumulate litter over successive years and can be creeping rooted. Annual species are cultivated and replanted yearly. Yearly incorporation of litter, combined with a bunchgrass growth habit, may result in lower litter and higher bare ground under annuals than under continuous perennial cover after several years.

Smooth bromegrass (*Bromus inermis* Leyss.) and meadow bromegrass (*Bromus riparius* Rehm.) are two perennial species commonly used for pasture in the Alberta parkland. Meadow bromegrass is weakly rhizomatous while smooth bromegrass is strongly rhizomatous. Smooth bromegrass is slow to regrow because most or all tiller apices are removed by cutting during initial growth (Casler and Carlson 1995) and regrowth comes from crowns and underground rhizomes. In contrast, meadow bromegrass retains more vegetative tillers than smooth bromegrass, so regrowth is faster (Baron 1992) and production is more uniform over the growing season (Pearen et al. 1995). Meadow bromegrass commences growth early in the spring and is ready to graze earlier than smooth bromegrass. It continues to grow during cooler fall weather, extending the grazing season and providing cover later into the season (Knowles et al. 1993). Stands of meadow bromegrass can be more difficult to establish than smooth bromegrass because meadow bromegrass lacks the aggressive creeping root habit of smooth bromegrass and thus vegetative enlargement is more limited (Pearen et al. 1995).

Triticale (*X Triticosecale* Whittmack) and barley (*Hordeum vulgare* L.) are annual grass species commonly used for pasture (Baron et al. 1993a). Triticale is an annual winter cereal with medium litter producing potential while barley is an annual spring cereal with low litter producing potential. Tillers tend to be more prostrate in triticale than in barley (Baron et al. 1993a) and remain vegetative throughout the growing season when spring-planted (Baron et al. 1993b). Like most winter cereals, triticale is productive into September and October on the Canadian prairies and parklands (Baron et al. 1993b). Barley is highly productive early in the growing season and has a more erect growth habit than triticale (Baron et al. 1993a). It produces a high proportion of floral tillers by mid-July and is less productive than winter cereals later in the growing season (Baron et al. 1993b).

It was hypothesized that biomass, leaf area index and litter would decrease and tiller number and bare ground would increase with increasing

grazing intensity for all forage species. It was also hypothesized that differences in litter biomass and bare ground would be greater between annual and perennial species than within each species type. These differences among individual species and between types of species may have an impact on soil erosion losses within an ecosystem. From that perspective, it is important to know how vegetation characteristics which affect erosion potential differ among these species with increased grazing intensity. Our objective was to measure total annual biomass, early and late season post-grazing biomass, leaf area index, spring and fall litter, total tiller number and bare ground for the four forages at three grazing intensities over a two-growing-season period.

2.2 Materials and Methods

2.2.1 Study Site

The study site is located at the Agriculture and Agri-Food Canada Research Centre, Lacombe, Alberta, at 24-40-27-W4 (52°27.5' N, 113°44' W). The climate is continental prairie and is mildly affected by chinook winds most winters (Environment Canada 1991). The moisture regime is sub-humid with 447.5 mm of precipitation annually (de St. Remy 1992). Mean annual temperature is 2.4 °C with a January mean of -13.6 °C and a July mean of 16.1 °C. The dominant soil in the area is an Orthic Black Chernozem developed on glacio-fluvial lacustrine parent material with a loam to sandy loam texture. Topography is undulating, with 1 to 3% slopes (Stalker 1960). Average elevation is 870 m above sea level.

Before being plowed in fall 1992, the study site vegetation was the same as an adjacent benchmark site, representative of pastures in the area. This benchmark site is a perennial grass pasture consisting of smooth bromegrass (*Bromus inermis* Leyss.), Kentucky bluegrass (*Poa pratensis* L.) and quack grass (*Agropyron repens* L.), which had been grazed approximately twice per growing season at a moderate to heavy intensity for 15 years. The benchmark site was used as a reference to assess initial soil conditions (Table 2.1), vegetation and soil changes over the study period and to represent long-term perennial pastures in the area.

2.2.2 Research Plot Design

The experimental design was a completely randomized block with twelve treatments in each of four blocks. The treatments represented combinations of three grazing intensities and four forage types (Figure 1, Appendix A). Each plot, representing one treatment, was approximately 9 by 33 m. The four blocks were placed one above the other across an east-facing slope at 866 to 873.5 m elevation. The upper two blocks were situated on a 4-6% portion of the slope, while the lower two blocks were on relatively flat land. Three pseudo-plots (B1, B2, B3) were established on a similar slope on an adjacent benchmark site. Data from this benchmark site were used to assess typical pasture management practices in the region but were not analysed statistically. Grazing enclosures consisting of four-strand barbed wire were erected around each study plot while the three plots on the benchmark site were unfenced. A solar powered electric fence was used in conjunction with the barbed wire fence to prevent cattle from grazing excessively in adjoining plots. Watering facilities were located at the downslope end of each treatment. The alleyways between blocks were sown to crested wheatgrass (*Agropyron cristatum* L.)

2.2.3 Forage Treatments

Four forage treatments with potentially differing abilities to control erosion and produce litter were used. 'Carlton' smooth bromegrass and 'Paddock' meadow bromegrass (*Bromus riparius* Rehm.) were the perennial treatments; 'Pika' triticale (*X Triticosecale* Whittmack) and a 'Pika' triticale/'AC Lacombe' barley (*Hordeum vulgare* L.) mix were the annual treatments.

Perennials were seeded on May 31, 1993. Seedbed preparation consisted of an application of 7-28-27-5 fertilizer at 112 kg ha^{-1}, one pass with a cultivator, followed by a diamond tooth harrow and a crowsfoot packer. Smooth bromegrass was seeded at 11.2 kg ha^{-1} and meadow bromegrass at 16.8 kg ha^{-1}. Spredor II alfalfa (*Medicago sativa* L.) was seeded with each grass at 1 kg ha^{-1}. Perennial plots were broadcast seeded with a Model HHBS-125 Handi-Spred Lawn and Garden Seeder-Spreader. Seeding was followed by one pass with a diamond tooth harrow and one pass with a crowsfoot packer. In the two subsequent years, perennial and annual plots were fertilized at the same time. In May 1994 and 1995, respectively, 22-10-22 and 20-10-20 fertilizers were applied at 560 kg ha^{-1}.

In the establishment year, triticale was planted in all annual plots, using the same method as for the perennial plots. In subsequent years, annual plots were seeded in early May at 135 kg ha^{-1} for triticale plots and 90 kg ha^{-1} triticale and 50 kg ha^{-1} barley for mixed plots. Residue (all above ground plant material after the last grazing of the previous season) remained in place until spring (end of April) seeding and the seedbed was prepared by cultivating, rototilling and fertilizing. Annual plots were seeded at 200 seeds per m^2 or 16 to 20 seeds per row-foot with a plot seeder with press wheels at the front and back of double disk openers. A herbicide (MCPA amine 500 at 200 ml ha^{-1}) was applied each year to annual plots after the crop emerged.

2.2.4 Grazing Treatments

The plots were grazed with one-year old crossbred beef replacement heifers. During the establishment year (1993), grazing was conducted to remove approximately half the biomass of establishing forages on all plots. Beginning in 1994, up to six animals were placed on a treatment at one time, depending on the intensity of grazing desired. Water was constantly available to cattle so as not to disrupt grazing habits and grazing events were never longer than 48 hours.

Grazing intensity was determined through target vegetation heights based on forage morphology, desired litter and bare ground appropriate for that treatment. Target and actual vegetation heights are given in Table 2.2. Heavy grazing represented an overgrazed condition with significant bare ground and a low amount of litter. Medium grazing represented a near optimum condition, without excessive bare ground and with a moderate amount of litter. Light grazing represented an advanced stage of forage maturity and a maximum amount of litter.

Vegetation height was used as an indicator for initiation and cessation of grazing and was measured with a disk meter consisting of a moveable aluminum plate on a central shaft. The plate was 35 cm in diameter and weighed 250 g (Bransby et al. 1977). Disk meter height was recorded as the height once the plate had fully settled atop the vegetation. Five random disk meter measurements were made per plot. Because different grazing intensities required different amounts of rest, heavily, medium and lightly grazed perennial plots received six to eight, five to six and three grazings per growing season,

respectively. Heavily, medium and lightly grazed annual plots received three to five, four and two grazings per growing season, respectively.

2.2.5 Meteorological Measurements

A meteorological station was established adjacent to the study site and included a Sierra-Misco Inc. Model RG2501 tipping bucket rain gauge to measure precipitation amounts and a Campbell Scientific Co. Model 101 temperature probe to monitor air temperature. This equipment was mounted on a Campbell Scientific Model CM10 tripod and connected to a Campbell Scientific Inc. Model CR21 micrologger. Data were downloaded via cassette twice monthly from the micrologger onto an IBM 486 computer with translation software. Snow accumulation was measured manually at a second meteorological station 1 km distant. Data collected from 1908 to 1992 at this second station were used for long-term normals.

2.2.6 Post-Grazing Vegetation Assessment

Vegetation Biomass

Biomass was randomly sampled immediately after each grazing in 1994 and 1995. A 1-m wide buffer strip around the edge of each plot was not sampled. Three 0.25-m^2 quadrats were clipped after each grazing but this sampling was inadequate to account for plot variability, especially in the medium and lightly grazed treatments where areas of vegetation were left untouched. Sampling procedure was changed on June 12, 1994 to include six 0.125-m^2 quadrats. Standing vegetation was clipped to within 1 cm of ground level within each quadrat, with care taken to exclude litter on the soil surface. A 250-g subsample was dried for 48 hours at 65 ^oC and then weighed to determine percent dry matter. Post-grazing biomass was the average biomass remaining per treatment after a grazing event while total annual biomass was the total biomass produced per treatment per growing season.

Leaf Area Index

Leaf area index was assessed each year on all plots after grazing using an LAI-2000 plant canopy analyzer consisting of an LAI-2070 control unit and an LAI-2050 optical sensor (Li-Cor Ltd., Lincoln, NE). Ten meter readings taken

a 1-m minimum from the edge of each plot were automatically averaged. This average was manually recorded.

2.2.7 Plant Species Composition and Vegetation Characteristics

Plant species composition was assessed within five randomly located 0.1-m^2 quadrats annually in mid-July. Ground cover (percent litter, live vegetation, bare ground, manure, rocks and moss at ground level), litter depth and canopy height were assessed in each quadrat. In 1994, separate sampling sites were selected for species composition, biomass and litter. Because sufficient growth occurred, biomass and litter sampling sites were not kept separate the following year. In both years, a 1-m wide buffer strip around the edge of each plot was not sampled.

2.2.8 Litter Biomass Sampling

In spring before first grazing and in fall after final grazing, three randomly located 0.05-m^2 areas were sampled in each plot. All plant material was clipped at ground level and the soil surface was raked with a hand-fork to remove all litter above the soil mineral surface. All material was collected and sorted into live and dead components. Any green material was considered live. Each component for each sample was oven dried at 65 °C for 48 hours and weighed to determine oven-dry litter weight.

2.2.9 Statistical Analyses

Leaf area index, bare ground, total tiller number and total biomass were analyzed within year using a two-way Analysis of Variance with forage species (f=4) and grazing intensity (g=3) as factors. Biomass data were grouped into early and late growing season and averaged across these groupings on a per plot basis with July 18 used as the demarcation date in 1994 and 1995. This date was roughly half-way through the growing season and bare ground assessments were conducted at this time both years. Most importantly, this date split the two grazings per year received by the lightly grazed treatments. Litter data were separated into spring and fall groupings prior to statistical analysis. Both litter and biomass were analysed by grouping within year using a two-way Analysis of Variance with forage species (f=4) and grazing intensity (g=3) as factors. SAS Software System was used to analyse biomass and litter data

(SAS Institute Inc. 1988). Data Desk 4.2 by Data Description, Inc. (Velleman 1995) was used to perform all other statistical analyses.

Residual versus predicted values were plotted to evaluate the variances of the statistical populations within each treatment (Ott 1993) and were randomly scattered, thus all data were analyzed without transformation (Finney 1989). Results were declared significant when $p \leq 0.05$. For significant sources of variation, differences among means were determined using Fisher's LSD procedure (Ott 1993) at $p \leq 0.05$. A standard error of the species by grazing means was reported for each analysis of variance. One standard error was reported where the means of each treatment combination were the same. Where the number of observations contributing to the means differed due to missing values, the largest and smallest standard errors were reported as a range. In 1994, leaf area index data were not analyzed due to missing values for heavily grazed meadow bromegrass and barley/triticale treatments.

2.3 Results and Discussion

2.3.1 Precipitation and Temperature

For 1994 summer months, precipitation was above the long term normal (Table 2.3). August 1994 was very wet and warm. In summer 1995, monthly precipitation was above the long term normal until September, when it dropped to only 21% of the long term normal. Monthly winter precipitation was at or below the long term normal throughout the study except in January 1994, November 1995 and January 1996 when precipitation was respectively 311, 213 and 172% of the long term normal.

2.3.2 Litter Biomass

In spring 1994, litter biomass did not vary with grazing intensity and was similar among forage species (Table 2.4). Thereafter, litter biomass generally decreased with increasing grazing intensity. A significant (α=0.05) forage by grazing effect was measured in fall 1994. Forage by grazing effect was also significant in spring and fall 1995. Treatment differences were more apparent in 1995 than 1994, with the highest levels of litter occurring in lightly grazed perennials and the lowest in heavily grazed barley/triticale, as expected. Litter had been incorporated yearly in annual treatments, whereas it had

accumulated over two years in perennial treatments by fall 1995, resulting in the higher levels under perennials. Decreased litter with increased grazing intensity has been measured in several other studies (Naeth et al. 1991, Rauzi 1963, Johnston 1962, Johnston 1961) in mixed grass prairie, parkland fescue grassland, dry mixed grass prairie and foothills fescue grassland.

2.3.3 Bare Ground

Bare ground ranged from 0.6 to 31.7% for perennials and 42.2 to 74.5% for annuals (Table 2.4). Bare ground under medium grazing was generally closer to that under light grazing than heavy grazing and the increases in bare ground between light and heavy grazing intensity were much greater under perennials. During both years of the study, bare ground was significantly greater (α=0.05) in annuals than perennials due to their yearly cultivation and planting. Forage by grazing interaction was significant (α=0.05) only in 1995. Bare ground generally increased with increased grazing intensity, especially in perennials, a trend reported in several other studies (Stewart and Forsling 1931, Packer 1953, Johnston 1962, Naeth et al. 1991). Some exceptions have been reported, however. Bare ground did not differ with grazing intensity in a grazing study of cool season grasses in northeast Saskatchewan (McCartney and Bittman 1994), perhaps because grazing intensities did not differ sufficiently to create bare ground differences. Heavy grazing involved only five grazings per year, whereas in our study up to eight grazings were conducted.

2.3.4 Plant Species Composition

Plant species composition was similar at medium and light grazing intensity in perennials (Table 2.5). Percent alfalfa and percent weed composition were greatest and percent bromegrass lowest at heavy grazing intensity in perennial treatments both years. This pattern was also observed in only one of four years in a study by McCartney and Bittman (1994) measuring weed invasion into cool-season grass pastures, with similar weed composition across grazing intensities for the other three years. Grazing intensity had no effect on weed composition in annuals because they had been sprayed. The highest weed composition for annuals was measured in heavily grazed barley/triticale in 1994.

In the barley/triticale mix, barley composition decreased and triticale composition increased with increasing grazing intensity both years (Table 2.5).

The competitive ability of triticale may have been reduced by shading from barley at lighter grazing intensities, reducing triticale in the sward (Baron et al. 1993a). As discussed by Trenbath (1974) and Donald (1963), tall species with leaves at the top of the canopy have a competitive advantage over shorter ones until defoliation reduces competition for light.

At the medium and heavy grazing intensities, the more prostrate triticale tillers were grazed less than erect barley tillers (Baron et al. 1993a), effectively maintaining triticale in the sward. Rhodes (1970) also found that species with higher tiller density and prostrate growth habit were more productive and dominant under frequent clipping regimes while tall, erect, sparsely tillering types were more suited to infrequent clipping.

2.3.5 Total Tiller Number

Total tiller number generally increased with decreasing grazing intensity both years (Table 2.6). This response is opposite to that measured by Hart et al. (1971) in tall fescue and orchardgrass swards as clipping height decreased and clipping frequency increased. It is possible that heavy grazing intensity in this study depleted energy stores to the point that initiation of new tillers was minimized compared to that for lower grazing intensities (Booysen and Nelson 1975).

Highest total tiller numbers were measured in lightly grazed triticale and meadow bromegrass both years, reflecting the more prostrate and leafy growth habit of these species than smooth bromegrass or barley. Smooth bromegrass was slower to regrow than meadow bromegrass both years. Van Esbroeck et al. (1995) also measured lower tiller density in smooth bromegrass than meadow bromegrass (var. Regar), due to a lower and more slowly increasing tiller density in smooth bromegrass in a clipping study at Lacombe, Alberta. Slower regrowth for smooth bromegrass than meadow bromegrass after grazing or cutting was also reported by King (1989), Baron (1992) and Pearen et al. (1995) in studies in Alberta.

In 1994, total tiller number was lowest for lightly grazed barley/triticale, while in 1995, total tiller number was lowest in medium grazed barley/triticale. In both cases, triticale tiller number was also lowest (data not shown) due to shading competition by the taller barley component (Baron et al. 1993a). Forage by grazing interaction was significant (α=0.05) in 1995 only.

2.3.6. Leaf Area Index

Leaf area index ranged from 1.5 to 4.6 in 1994 (Table 2.6). Data were not analysed in 1994 because of missing values, but generally decreased with increasing grazing intensity. In 1995, leaf area index generally decreased with increasing grazing intensity and was greatest in lightly grazed meadow bromegrass and triticale treatments. A significant forage by grazing interaction was measured for leaf area index in 1995.

Greater leaf area index was measured in medium and lightly grazed triticale versus corresponding barley/triticale treatments in 1995. Baron et al. (1993a) also measured higher leaf area index for winter cereals than winter/spring cereal mixes in a simulated pasture study at Lacombe, Alberta. Because winter cereals were totally vegetative, new leaves and tillers were regenerated after cutting, whereas barley had little energy to regrow once reproductive tillers were removed.

2.3.7. Early and Late Season Post-Grazing Biomass

Post-grazing biomass generally increased with decreasing grazing intensity as expected and was consistently greatest at light grazing intensity in all forages in early and late season 1994 (Table 2.7). In early season 1994, post-grazing biomass was greater for smooth bromegrass than any other species at light grazing intensity and greater for perennials than annuals at medium grazing intensity. Post-grazing biomass was consistently lowest for heavily grazed meadow bromegrass after early season 1994.

In both early and late season 1995, post-grazing biomass was greatest at light grazing intensity in all forages. Post-grazing biomass for each treatment combination was lower in late season than early season in 1995 due to drought conditions in September of that year. Forage by grazing interaction was significant (α=0.05) for all data.

2.3.8. Total Annual Biomass

Total annual biomass was generally greater for perennials than annuals both years (Table 2.7). There was no clear pattern of variation of total annual biomass with grazing intensity in either year. Forage by grazing interaction and block effect were significant in (α=0.05) 1995 only. In 1994, total annual biomass was greatest in heavily grazed meadow bromegrass and least in

lightly grazed triticale. Total annual biomass was greatest for lightly grazed perennials and least for heavily grazed barley/triticale and lightly grazed triticale in 1995.

Baron et al. (1993b) measured greater annual yield in spring and winter cereal intercrops than in winter cereal monocrops under simulated pasture at Lacombe. A pattern of greater yield in the spring and winter cereal intercrop than in the winter cereal monocop was not measured in this study. It is interesting that increased grazing intensity did not result in lower total yields as found in other pasture studies (Edmond 1963, 1966, 1970). Damage in Edmond's studies was maximized during wet soil conditions, a situation not consistently present in this study.

2.3.9 Benchmark Site

The benchmark site represents one possible outcome of continued grazing on the study plots. Litter levels on the benchmark site were within the same range as those in medium grazed perennial treatments (Table 2.8). Because of the age of the stand, litter on the benchmark site formed a thick thatch, decreasing percent bare ground to almost zero. Weed cover on the benchmark site consisted chiefly of quackgrass (*Elytrigia repens* (L.) Nevski) and Kentucky bluegrass (*Poa pratensis* L.) and was much higher than in treatment plots (Table 2.9). Litter buildup, reduction in bare ground and weed invasion appear to be important factors influencing perennial pastures in this region as they age.

Species composition varied widely between years on the benchmark site. Species occurred in small patches, thus composition appeared variable when sampled with small (0.1-m^2) quadrats.

2.3.10 Vegetation Characteristics and Soil Erosion

Vegetation characteristics changed with increased grazing intensity to a different degree in each species. The direction of change was, however, generally the same. As grazing intensity increased, more forage was removed from swards that had undergone less regrowth, resulting in less carryover and less litter returned to the soil surface. Higher bare ground in annuals than perennials, very low post-grazing biomass in heavily grazed meadow bromegrass and reduction in tillering with increased grazing intensity,

especially in smooth bromegrass and barley/triticale, could result in unacceptably high erosion risk because of minimal surface cover.

Maintenance of soil surface cover is vital to soil erosion prevention. When vegetative cover is reduced through grazing, bare ground increases, along with a risk of water erosion (Packer 1953). The soil surface is exposed to raindrop impact and water flows overland instead of infiltrating (Rauzi and Hanson 1966). Recommendations to maximize pasture productivity (Matches 1992) can be used as guidelines for maintaining a healthy and vigorous sward to protect against water erosion. These are: (i) minimize the removal of shoot apices during the vegetative stage, (ii) maintain carbohydrate reserves at high levels, and (iii) do not reduce leaf area index excessively by defoliation.

2.4 Conclusions

1. Bare ground increased with increased grazing intensity and was significantly greater in annuals than perennials at all grazing intensities. Bare ground differences were less within than between annuals and perennials.

2. Total number of tillers and leaf area index decreased with increasing grazing intensity and were highest for lightly grazed meadow bromegrass and triticale.

3. Early and late season post-grazing biomass decreased with increasing grazing intensity and was least in heavily grazed meadow bromegrass after early season 1994.

4. Litter biomass decreased with increasing grazing intensity and was generally similar in all species both years at heavy and medium grazing intensity. At heavy grazing intensity, litter biomass was generally greater in perennials than annuals, especially in the second year of the study.

5. Total annual biomass was greatest for perennial species and generally did not differ with grazing intensity.

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Table 2.1. Initial soil characteristics on study and benchmark sites, 1993.

Soil Depth (cm)	pH	EC (dS m^{-1})	P (ppm)	K ($\mu g\ g^{-1}$)	S (ppm)	Carbon (%)	N (%)	SAR
Benchmark Site								
0-5	4.7	0.17	91.6	335.4	428.1	6.48	0.60	1.4
5-15	5.1	0.18	50.3	93.7	351.9	3.87	0.29	1.6
15-30	5.5	0.09	24.3	78.9	323.0	3.35	0.25	-
30-45	5.9	0.07	14.2	71.0	266.5	2.31	0.18	-
45-60	6.0	0.07	6.7	67.7	258.2	1.37	0.11	-
Study Plots								
0-5	5.2	0.73	167.0	885.4	429.6	5.75	0.47	1.4
5-15	5.5	0.24	117.4	344.5	444.2	4.86	0.38	1.4
15-30	6.2	0.18	43.8	182.5	334.8	3.29	0.27	-
30-45	6.7	0.14	14.5	121.9	244.1	1.64	0.14	-
45-60	7.0	0.13	8.2	128.3	200.5	0.84	0.08	-

EC = Electrical conductivity.
SAR = Sodium adsorption ratio.

Table 2.2. Average initiation and cessation heights for grazing, 1994 and 1995.

Treatment	Height At Which Grazing Initiated (cm)		Height At Which Grazing Ceased (cm)	
	Target	Actual	Target	Actual
Smooth Bromegrass				
Heavy	8-10	13.9	2.5	7.2
Medium	12-15	20.6	8-10	11.1
Light	20	37.2	12-15	13.9
Meadow Bromegrass				
Heavy	8-10	12.2	2.5	5.3
Medium	12-15	18.2	8-10	8.5
Light	20	25.5	12-15	9.3
Barley/Triticale				
Heavy	8-12	13.6	2.5	5.1
Medium	12-15	18.2	8-10	7.0
Light	15-20	40.1	12-15	13.5
Triticale				
Heavy	8-12	9.9	2.5	4.5
Medium	12-15	12.1	8-10	6.4
Light	15-20	18.5	12-15	7.8

Table 2.3. Mean daily temperature and monthly precipitation, October 1993 to April 1996, and long-term averages at Lacombe.

Month	Mean daily temperature (^{o}C)			Summer Precipitation (mm)			Month	Winter Precipitation (mm)			
	1994	1995	LTN[a]	1994	1995	LTN[a]		1993/94	1994/95	1995/96	LTN[a]
May	11	10	10	86	61	50	November	17	9	34	16
June	14	15	14	102	83	82	December	5	5	11	17
July	17	14	16	87	112	78	January	56	7	31	18
August	19	12	15	151	104	64	February	6	3	0	17
September	12	11	10	68	9	42	March	5	7	10	19
October	4	3	5	29	17	19	April	5	25	11	28
Average	13	11	12	-	-	-					
Total				523	386	335		94	49	97	100

[a] LTN = long term normal (1908 to 1992) recorded at the Lacombe Research Centre.

Table 2.4. Litter and bare ground for forage by grazing treatments, 1994 and 1995.

	Litter ($Mg\ ha^{-1}$) 1994		Litter ($Mg\ ha^{-1}$) 1995		Bare Ground (%)	
	Spring	Fall	Spring	Fall	1994	1995
Smooth Bromegrass						
Heavy	3.91 ab	4.47 cdef	3.78 cde	5.77 bcd	18.2 e	26.7 d
Medium	3.74 ab	6.71 bc	3.89 cde	8.48 ab	5.8 ef	2.5 e
Light	3.65 ab	11.05 a	5.58 ab	8.73 a	4.4 f	0.6 e
Meadow Bromegrass						
Heavy	3.09 b	4.17 def	2.30 ef	5.58 cd	30.6 d	31.7 d
Medium	3.57 b	6.76 b	4.46 bc	3.83 def	9.8 ef	6.3 e
Light	3.27 b	7.26 b	6.92 a	7.67 abc	12.0 ef	3.7 e
Barley/Triticale						
Heavy	3.63 ab	3.31 f	2.07 f	4.83 d	60.9 a	61.8 b
Medium	3.82 ab	4.34 def	2.49 def	1.95 ef	48.0 bc	74.5 a
Light	4.16 ab	7.39 b	4.52 bc	4.56 de	52.4 abc	44.8 c
Triticale						
Heavy	4.42 ab	5.91 bcd	2.39 def	1.85 f	53.8 ab	71.4 ab
Medium	4.96 a	3.76 ef	3.79 cd	4.16 def	42.2 c	67.6 ab
Light	4.42 ab	5.68 bcde	4.07 c	5.32 cd	48.3 bc	66.3 ab
SEM	0.49-0.57	0.69-0.80	0.53-0.61	0.96-1.1	4.0-4.7	4.1-4.7

Means within a column followed by the same letter are not significantly different at $p \leq 0.05$.
SEM: Standard error of the forage by grazing means within a column.

Table 2.5. Percent species composition for forage by grazing treatments, 1994 and 1995.

	1994			1995		
	Bromegrass	Alfalfa	Weeds	Bromegrass	Alfalfa	Weeds
Smooth Bromegrass						
Heavy	57.5	16.8	25.8	78.7	6.8	14.7
Medium	90.7	7.1	2.2	96.6	1.8	1.6
Light	87.4	10.0	2.7	90.5	3.8	5.8
Meadow Bromegrass						
Heavy	76.2	11.3	12.6	82.2	5.6	12.2
Medium	93.2	4.4	2.5	97.9	1.6	1.8
Light	94.4	3.9	1.8	97.0	2.9	0.2
	Barley	Triticale	Weeds	Barley	Triticale	Weeds
Barley/Triticale						
Heavy	32.5	56.5	11.1	34.0	60.7	0.4
Medium	44.6	55.3	0.1	45.8	53.7	0.6
Light	57.8	40.0	2.2	63.3	36.4	0.3
Triticale						
Heavy	N/A	99.8	0.2	N/A	100.0	0.0
Medium	N/A	100.0	0.1	N/A	94.1	5.9
Light	N/A	100.0	0.0	N/A	95.8	4.3

N/A: Not applicable for treatment.
No statistical analysis was performed on weed data because of herbicide application on annuals.

Table 2.6. Average number of total tillers and leaf area index for forage by grazing treatments, 1994 and 1995.

	Total Number of Tillers 0.375 m^{-2}		Leaf Area Index	
	1994	1995	1994	1995
Smooth Bromegrass				
Heavy	34.3 c	53.3 de	1.5	1.6 cd
Medium	40.7 c	61.0 bcde	2.5	2.1 b
Light	47.8 abc	64.7 bcde	3.3	2.1 b
Meadow Bromegrass				
Heavy	33.8 c	54.4 de	x	1.7 c
Medium	61.9 ab	62.1 bcde	2.6	1.8 bc
Light	69.4 a	92.3 ab	4.6	2.6 a
Barley/Triticale				
Heavy	45.7 bc	48.4 de	x	1.5 cd
Medium	50.7 abc	36.9 e	2.2	1.5 cd
Light	29.5 c	85.4 abc	3.8	2.0 bc
Triticale				
Heavy	32.0 c	74.1 bcd	2.3	1.3 d
Medium	64.1 a	78.3 bc	2.7	2.1 b
Light	70.6 a	112.7 a	4.4	2.8 a
SEM	4.7-9.3	7.3-13.6		0.1-0.25

x denotes missing value.
Means within a column followed by the same letter are not significantly different at $p \leq 0.05$.
SEM: Standard error of the forage by grazing means within a column.

Table 2.7. Early and late season post-grazing biomass and total annual biomass for forage by grazing treatments, 1994 and 1995.

	Post-Grazing Biomass (Mg ha^{-1})				Total Annual Biomass (Mg ha^{-1})	
	1994		1995			
	Early*	Late*	Early*	Late*	1994	1995
Smooth Bromegrass						
Heavy	0.60 e	0.87 fg	1.12 e	1.03 bc	10.64 bc	9.00 b
Medium	2.11 c	1.75 de	1.48 cd	0.80 cd	10.70 bc	9.91 b
Light	4.71 a	2.22 bc	2.84 a	1.67 a	12.59 ab	13.66 a
Meadow Bromegrass						
Heavy	0.92 de	0.61 g	0.73 f	0.53 d	13.84 a	6.81 cd
Medium	2.08 c	1.75 de	1.47 d	1.00 bc	10.49 bc	9.21 b
Light	3.55 b	2.93 a	1.98 bc	1.50 a	11.92 ab	13.25 a
Barley/Triticale						
Heavy	0.64 e	0.91 fg	1.07 ef	0.78 bcd	10.92 bc	4.91 e
Medium	0.97 de	1.58 e	0.99 ef	0.87 bcd	8.97 c	5.45 de
Light	3.32 b	2.98 a	3.19 a	1.35 ab	9.10 c	8.50 bc
Triticale						
Heavy	0.64 e	0.98 f	1.16 de	0.88 bcd	9.10 c	9.12 b
Medium	1.18 d	2.07 cd	1.94 bc	1.59 a	9.51 c	5.60 de
Light	2.41 c	2.59 ab	2.21 b	1.71 a	8.94 c	4.87 e
SEM	0.13-0.25	0.11-0.22	0.10-0.20	0.13-0.22	0.80-0.92	0.64-0.74

* July 18 separates Early from Late grazing.
Means within a column followed by the same letter are not significantly different at $p \leq 0.05$.
SEM: Standard error of the forage by grazing means within a column.

Table 2.8. Bare ground, litter and weed invasion on the benchmark site, 1994 and 1995.

Year	Spring Litter Mg ha^{-1}	Fall Litter Mg ha^{-1}	Bare Ground (%)	Percent Weeds (%)
1994	5.5	6.4	0.2	80.3
1995	6.0	3.5	0.1	55.3

Table 2.9. Benchmark site percent species composition.

Species	1994	1995
Smooth Bromegrass (*Bromus inermis* Leyss.)	19.6	40.6
Kentucky Bluegrass (*Poa pratensis* L.)	53.0	36.8
Quackgrass (*Elytrigia repens* L.)	27.3	17.9
Bluegrass Species (*Poa spp.*)	0.0	4.2
Dandelion (*Taraxacum officinale* L.)	0.1	0.0

CHAPTER 3

RUNOFF AND SEDIMENT YIELD DURING SNOWMELT AND RAINFALL EVENTS AS INFLUENCED BY FORAGE TYPE AND GRAZING INTENSITY

3.1. Introduction

Annual and perennial forages are used for cattle grazing in the parkland of Alberta. The region is dominated by snowmelt runoff (Harms 1996), with rainfall runoff occurring from convective precipitation (Tajek et al. 1985). Because annual forages can be more productive than perennial forages at different times during the growing season, they can play a vital role in reducing grazing pressure, and thus soil erosion risk, on permanent pastures (Baron et al. 1993a). However, little is known about the direct conservation potential of annual forages in the parkland ecoregion of Alberta.

Perennial forages are traditionally associated with soil conservation (Browning 1973, Van Doren and Triplett 1982), providing year-round surface cover, minimizing raindrop impact and preventing soil aggregate breakdown. Surface litter is generated which helps curtail runoff. This is especially important during snowmelt and times of intense precipitation and/or high antecedent soil water. Because annual forages are managed differently than perennial forages, their contribution to soil conservation is possibly quite different. Annual pastures are generally cultivated each spring and a new crop is planted. Thus, the soil surface is bare and loose during a time when rainfall events of significant intensity and duration commonly occur (Alberta Agriculture 1991). When the forage emerges, the row pattern of the forage may exacerbate rill erosion through channelling of water along rows.

Four species used for pasture in the parkland ecoregion of Alberta are smooth bromegrass (*Bromus inermis* Leyss.), meadow bromegrass (*Bromus riparius* Rehm.), triticale (*X Triticosecale* Whittmack) and barley (*Hordeum vulgare* L.) (Beacom 1991, Baron et al. 1993a, Knowles et al. 1993). Smooth bromegrass is rhizomatous and has medium litter producing potential. It can be slow to regrow after cutting or grazing because most or all tiller apices are removed and regrowth must develop from buds at belowground nodes (Casler

and Carlson 1995). Meadow bromegrass is weakly rhizomatous and has high litter producing potential. It commences growth early in the spring and continues to grow during cooler fall weather, providing cover later into the season (Knowles et al. 1993). Stands of meadow bromegrass can be more difficult to establish than smooth bromegrass because meadow bromegrass lacks the aggressive creeping root habit of smooth bromegrass and thus vegetative enlargement is more limited (Pearen et al. 1995). Triticale is a winter cereal with medium litter producing potential. Tillers tend to be more prostrate in triticale than in barley (Baron et al. 1993b) and remain vegetative throughout the growing season when spring-planted (Baron et al. 1993a). Like most winter cereals, triticale is productive into September and October on the Canadian prairies and parklands (Baron et al. 1993a). Barley is a spring cereal which is highly productive early in the growing season and has a more erect growth habit than triticale (Baron et al. 1993b). By seeding triticale and barley together in a sward, the land may be maintained under vegetative cover a greater portion of the growing season, reducing soil erosion risk (Baron et al. 1993a).

Grazing modifies the influence of a forage crop on soil erosion through biomass and litter removal. Height of standing and fallen litter, biomass and live vegetation cover generally decrease with a progressive increase in grazing intensity (Packer 1953, Naeth et al. 1991a). At high grazing intensities, bare ground increases with a concurrent increase in susceptibility to raindrop impact and aggregate breakdown (Duley and Kelly 1939 as cited by Troeh et al. 1980, Kincaid and Williams 1966). As aggregates break down, small soil particles may be washed down into soil pores, reducing infiltration and causing increased runoff (Troeh et al. 1980).

Surface litter protects the soil from raindrop impact, provides cushioning against animal hoof impact and improves aggregation through addition of organic matter. A thick litter layer also increases roughness, slowing down surface flow, causing sediments to drop out of suspension and increasing infiltration (Besler 1987). Low grazing pressure resulting in excessive accumulations of litter may lead to lower soil moisture (Naeth et al. 1991b). A thick litter layer may be hydrophobic when dry and may retain moisture when wet (Naeth et al. 1991c). The vigor of the sward may be reduced when the litter layer is excessive because of decreased seed germination and reduced tillering. Trampling and removal of litter by cattle counteracts this buildup. Ideally, grazing pressure should optimize the balance between litter removal

and buildup, with productivity remaining high without affecting soil quality (Packer 1953, Naeth et al. 1991a).

The effect of grazing intensity on runoff and sediment yield has been studied for several soil and vegetation types. In Canadian parkland fescue and foothills fescue grasslands on Orthic Black Chernozems and mixed prairie grasslands on Brown Solods and Solodized Solonetzes, Naeth et al. (1990a) measured greater infiltration in ungrazed or lightly grazed treatments than heavily grazed treatments. On Orthic Black Chernozems under foothills fescue grasslands, Naeth and Chanasyk (1996) reported that runoff, sediment yield, sediment concentration and runoff coefficients were generally lower in ungrazed treatments than in heavy or very heavy grazed treatments. Van Doren et al. (1940) found that grazing management did not significantly affect runoff on 2-year old improved pasture on eroded silt loam soils in Illinois. Stewart and Forsling (1931) reported that runoff and sediment increased with decreased plant cover for both rainfall and snowmelt on high elevation native range in Utah. Sallaway and Waters (1994) measured an increase in runoff with increased grazing intensity on black speargrass rangelands in Australia. On clay loam soils in annual Mediterranean grassland, Liacos (1962) found that runoff was greater for heavy grazed than for ungrazed treatments.

Our hypothesis was that species would differ in erosion control capability due to differences in biomass and amount of associated bare ground and that erosion would increase with increasing grazing intensity. We hypothesized that efficacy in erosion control would be as follows: smooth bromegrass > meadow bromegrass > triticale > barley/triticale. To test these hypotheses, our research objectives were;

1. To quantify runoff and sediment yield under snowmelt and rainfall events under three grazing intensity treatments and four forage species treatments.
2. To determine and measure relationships between litter, biomass, bare ground and leaf area index and runoff and sediment yield for each forage species.

3.2. Materials And Methods

3.2.1 Study Site

The study site is located at the Agriculture and Agri-Food Canada Research Centre, Lacombe, Alberta, at 24-40-27-W4 (52°27.5' N, 113°44' W). The climate is continental prairie and is mildly affected by chinook winds most winters (Environment Canada 1991). The moisture regime is sub-humid with 447.5 mm of precipitation annually (de St. Remy 1992). Mean annual temperature is 2.4 °C with a January mean of -13.6 °C and a July mean of 16.1 °C. The dominant soil in the area is an Orthic Black Chernozem developed on glacio-fluvial lacustrine parent material with a loam to sandy loam texture. Topography of the area is undulating, with 1 to 3% slopes (Stalker 1960). Average elevation is 870 m above sea level.

Before being plowed in fall 1992, the study site vegetation was the same as an adjacent benchmark site, representative of pastures in the area. This benchmark site was a 15 year old perennial grass cover consisting of smooth bromegrass (*Bromus inermis* Leyss.), Kentucky bluegrass (*Poa pratensis* L.) and quack grass (*Agropyron repens* L.), which had been grazed approximately twice per growing season at a moderate to heavy intensity. The benchmark site was used as a reference to assess initial soil conditions (see Table 2.1, Chapter 2) and vegetation and soil changes over the study period and to provide comparison with long-term perennial pastures in the area.

3.2.2 Research Plot Design

The experimental design was a completely randomized block with twelve treatments in each of four blocks. The treatments represented combinations of three grazing intensities and four forage types (Figure 1, Appendix A). Each plot, representing one treatment, was approximately 9 by 33 m. The four blocks were placed one above the other across the same east-facing slope at an 866 to 873.5 m elevation. The upper two blocks were situated on a 4 to 6% portion of the slope, while the lower two blocks were on relatively flat land. Three plots (B1, B2 and B3) were established on as similar a slope as possible on the adjacent benchmark site. Grazing enclosures, consisting of four-strand barbed wire and a solar powered electric fence, were erected around each study plot while the three plots on the benchmark site were unfenced. Watering facilities were included at the base of each plot.

Continuous soil berms 25 cm high were made across the top of each block to prevent surface runoff entering from uphill. This minimized extraneous runoff into each plot. The side of the berm within a plot was vegetated with the species sown in that plot, otherwise smooth bromegrass was used. The alleyways between blocks were sown to crested wheatgrass (*Agropyron cristatum* L.).

3.2.3 Forage Treatments

Four forage treatments with potentially differing abilities to control erosion and produce litter were used. 'Carlton' smooth bromegrass and 'Paddock' meadow bromegrass (*Bromus riparius* Rehm.) were the perennial treatments; 'Pika' triticale (*X Triticosecale* Whittmack) and a 'Pika' triticale/'AC Lacombe' barley (*Hordeum vulgare* L.) mix were the annual treatments. Perennials were seeded on May 31, 1993. Seedbed preparation consisted of an application of 7-28-27-5 fertilizer at 112 kg ha^{-1}, one pass with a cultivator, followed by a diamond tooth harrow and a crowsfoot packer. Smooth bromegrass was seeded at 11.2 kg ha^{-1} and meadow bromegrass at 16.8 kg ha^{-1}. 'Spredor II' alfalfa (*Medicago sativa* L.) was seeded with each grass at 1 kg ha^{-1}. Perennial plots were broadcast seeded with a Model HHBS-125 Handi-Spred Lawn and Garden Seeder-Spreader. Seeding was followed by one pass with a diamond tooth harrow and one pass with a crowsfoot packer. In subsequent years, perennial and annual plots were fertilized at the same time. In May 1994 and 1995, respectively, 22-10-22 and 20-10-20 fertilizers were applied at 560 kg ha^{-1}.

In the establishment year, triticale was planted in all annual plots, using the same method as for the perennial plots. In subsequent years, annual plots were seeded in early May at 135 kg ha^{-1} for triticale plots and 90 kg ha^{-1} triticale and 50 kg ha^{-1} barley for mixed plots. Residue (all above ground plant material remaining after the last grazing of the previous season) was left in place until spring (end of April) seeding and the seedbed was prepared by cultivating, rototilling and fertilizing. Annual plots were seeded at 200 seeds per m^2 or 16 to 20 seeds per row-foot with a plot seeder with press wheels at the front and back of double disk openers. A herbicide (MCPA amine 500 at 200 ml ha^{-1}) was applied each year to annual plots after the crop emerged.

3.2.4 Grazing Treatments

The plots were grazed with one-year old crossbred beef replacement heifers. During the establishment year (1993), grazing was conducted to remove approximately half the biomass of establishing forages on all plots. Beginning in 1994, up to six animals were placed on a treatment at one time, depending on the intensity of grazing desired. Water was constantly available to cattle so as not to disrupt grazing habits. Grazing events were never longer than 48 hours.

Grazing intensity was determined through target vegetation heights based on forage morphology, desired litter and bare ground appropriate for that treatment. Target and actual vegetation heights are given in Table 2.2, Chapter 2. Heavy grazing represented an overgrazed condition with significant bare ground and a low amount of litter. Medium grazing represented a near optimum condition, without excessive bare ground and with a moderate amount of litter. Light grazing represented an advanced stage of forage maturity and a maximum amount of litter.

Vegetation height was used as an indicator for initiation and cessation of grazing and was measured with a disk meter consisting of a moveable aluminum plate on a central shaft. The plate was 35 cm in diameter and weighed 250 g (Bransby et al. 1977). Disk meter height was recorded as the height once the plate had fully settled atop the vegetation. Five random disk meter measurements were made per plot. Because different grazing intensities required different amounts of rest, heavily, medium and lightly grazed perennial plots received six to eight, five to six and three grazings per growing season, respectively. Heavily, medium and lightly grazed annual plots received three to five, four and two grazings per growing season, respectively.

3.2.5 Meteorological Measurements

A meteorological station was established adjacent to the study site and included a Sierra-Misco Inc. Model RG2501 tipping bucket rain gauge to measure precipitation amounts and a Campbell Scientific Co. Model 101 temperature probe to monitor air temperature. This equipment was mounted on a Campbell Scientific Model CM10 tripod and connected to a Campbell Scientific Inc. Model CR21 micrologger. Data were downloaded via cassette twice monthly from the micrologger onto an IBM 486 computer with translation software. Snow accumulation was measured manually at a second

meteorological station 1 km distant. Data collected from 1908 to 1992 at this second station were used for long-term normals.

3.2.6 Runoff and Sediment Measurement

Runoff Frame Installation

One 1-m^2 runoff frame was installed between the centre and upper third of each plot in the first and second replicates of the study site in summer 1993. Three runoff frames were installed on the benchmark site. All frames were installed so spouts drained directly downslope (Figure 2, Appendix A).

A hole to accommodate a 60-L plastic bucket was dug in the ground and each runoff frame pounded into the ground upslope of the hole so one half to one third of the frame's metal edge protruded evenly above the soil surface. A hole was cut in the side of a 60-L bucket to fit a corrugated plastic drainage hose attached to the runoff frame spout and caulked. A 22.73-L bucket was placed inside the 60-L bucket and a lidded 4-L pail was placed inside this. The hose from the runoff spout was inserted through a hole in the lid of the 4-L pail. Three mothballs held in cheesecloth were attached to the underside of the 4-L pail lid to discourage rodents from entering and nesting. A lid was placed on the 60-L pail and the soil was tamped down around the bucket and its handles secured into the ground with metal pegs. A 0.5-m long and 8-cm deep drainage channel was dug downslope from the lip of the bucket to prevent water from collecting around the top of the 60-L bucket and seeping under the lid. The embedded bucket was covered with a 2-cm thick sheet of particle board approximately 0.75 m^2. A rubber cover made of old tire inner tubing was fastened over the portion of the particle board trimmed away to accommodate the runoff frame spout.

Runoff Frame Seeding

Annuals were hand seeded in runoff frames each spring after hand digging and raking the soil. Seed was broadcast at 200 seeds m^{-2}, raked in and foot pressed to pack the soil surface. After emergence, vegetation was thinned to 150 plants m^{-2}. Poor forage emergence in 1995 necessitated replanting on June 3, 1995 and again on July 6, 1995. The forage replanted within the frames was watered after the July 6 planting to ensure germination and establishment.

Snowmelt and Rainfall Runoff Measurement

Runoff was collected in March 1994 and 1995. In 1994, three sample bottles of 270 ml each were taken from each plot whenever at least 1 L of runoff had been collected. In 1995, 1-L samples were collected. Where less than 1 L of runoff accrued, the entire amount was taken as a sample. Runoff was stirred to suspend sediments before sample bottles were filled. Runoff volume was measured with a 250-ml graduated cylinder a maximum of twice daily and collection buckets were emptied and wiped clean with paper towel.

Rainfall runoff collection after each precipitation event began in May 1994 and April 1995 using the same sampling procedure for snowmelt. In both years, where less than 200 ml of runoff accrued, the water volume was measured but the sample was not saved for sediment analysis.

Sediment samples were refrigerated until analyzed. A 9-cm Buchner funnel and 500-ml vacuum flask arrangement using pre-weighed #4 qualitative filters was attached to a vacuum line to filter samples (Figure 3, Appendix A). After rinsing with de-ionized water, the filter was placed in a pre-weighed beaker, covered and dried in an oven set at 75 °C for 48 hours then weighed to the nearest 0.0001 g.

3.2.7 Vegetation Assessments

Post-Grazing Biomass

Biomass randomly sampled immediately after each grazing in 1994 and 1995 provided an assessment of the minimum amount of biomass available to protect against erosion from rainfall events. Biomass data were divided into early and late growing season groupings with July 18 used as the demarcation date both years. This date was roughly half-way through the growing season and bare ground assessments were conducted at this time both years. Most importantly, the two grazings per year received by lightly grazed treatments fell one on either side of this date.

A 1-m wide buffer strip around the edge of each plot was not sampled. Three 0.25-m^2 quadrats were clipped after each grazing but this sampling was inadequate to account for plot variability, especially in the medium and lightly grazed treatments where areas of vegetation were left untouched. Sampling procedure was changed on June 12, 1994 to include six 0.125-m^2 quadrats. Standing vegetation was clipped to within 1 cm of ground level within each

quadrat, with care taken to exclude litter on the soil surface. A 250-g subsample was dried for 48 hours at 65 °C and then weighed to determine percent dry matter.

Leaf Area Index

Leaf area index was assessed each year on all plots after each grazing using an LAI-2000 plant canopy analyzer consisting of an LAI-2070 control unit and an LAI-2050 optical sensor (Li-Cor Ltd., Lincoln, NE). Ten meter readings taken at random a 1-m minimum distance from the edge of each plot were automatically averaged and manually recorded.

Bare Ground Measurements

Bare ground was assessed in five randomly located 0.1-m^2 quadrats per plot once annually in mid-July. In 1994, sampling sites were selected to prevent bare ground sampling from coinciding with biomass and litter sampling. Because sufficient growth had occurred, biomass and litter sampling sites were not kept separate the following year. In both years, a 1-m wide buffer strip around the edge of each plot was not sampled.

Litter Biomass Sampling

In spring before first grazing and in fall after final grazing, three randomly located 0.05-m^2 samples were taken in each plot. All plant material was clipped at ground level and the soil surface was raked with a hand-fork to remove all litter above the soil mineral surface. All material was collected and sorted into live and dead components. Any green material was considered live. Each component for each sample was oven dried at 65 °C for 48 hours and weighed.

3.2.8 Statistical Analyses

Runoff was expressed in L m^{-2} and sediment yields in kg ha^{-1}. Sediment concentration in 10^{-4} kg L^{-1} was calculated from total water and total sediment yield per plot while runoff coefficients (rainfall events only), in mm of runoff per mm precipitation, were averaged over all observations. Data Desk 4.2 by Data Description, Inc. (Velleman 1995) was used to perform statistical analyses. Two-way ANOVA with interactions was performed and residual versus predicted values were plotted to evaluate the variances of the statistical populations within each forage treatment (Box 1954, Ott 1993). High variances were noted, particularly in populations consisting of many zeros and a few large values. No

transformation was satisfactory because the relationship between treatments was distorted by any form of transformation (Finney 1989), thus the data were analyzed without transformation. Standard error was reported for each two-way ANOVA. For significant sources of variation, differences among means were determined using Fisher's LSD procedure (Ott 1993) at $p \leq 0.05$.

Pearson product moment correlation analysis was performed within each forage between total rainfall runoff and sediment, bare ground, early and late biomass, fall litter, leaf area index and average antecedent soil water for 1994 and 1995. Total snowmelt runoff and sediment within each forage were correlated with spring litter for each year. Correlations were declared significant at $p \leq 0.05$.

3.3. Results And Discussion

3.3.1 Meteorological Parameters

For all summer months in 1994, precipitation was above the long term normal (Table 2.3, Chapter 2). August 1994 was very wet and warm. In summer 1995, monthly precipitation was above the long term normal until September, when it dropped to only 21% of the long term normal. Monthly winter precipitation was at or below the long term normal throughout the study except in January 1994, November 1995 and January 1996 when precipitation was respectively 311, 213 and 172% of the long term normal.

3.3.2 Total Runoff

No clear trend with grazing intensity was evident for snowmelt or rainfall total runoff (Table 3.1). No significant treatment differences were measured in total snowmelt runoff either year. Total snowmelt runoff was generally greater than total rainfall runoff (Table 3.2). Manner of water delivery was the characteristic which most likely increased snowmelt runoff above that for rainfall. Snowmelt was an intense event; a large volume of water was incident on the soil surface in a short time period and the ground was frozen, which increased runoff by limiting infiltration. Higher runoff for snowmelt than rainfall was also measured by Wilcox (1994) and Naeth and Chanasyk (1996).

In contrast to snowmelt, rainfall was dispersed throughout the growing season on non-frozen soil. Because the soil was well aggregated, infiltration was quite high when the soil was not frozen and thus total rainfall runoff values

were generally low. Total 1994 rainfall runoff was statistically similar in all treatments except heavily grazed barley/triticale (Table 3.1). The significantly higher runoff for this latter treatment arose from one rainfall event in August 1994 during which rainfall intensity peaked in a 15-minute interval at 72 mm h^{-1}. A significant forage by grazing interaction was measured for total rainfall runoff in 1994. Total rainfall runoff decreased with decreasing grazing intensity for perennial treatments in 1995 and was highest for heavily grazed perennials. Abdel-Magid et al. (1987) measured increased runoff with increased bulk density in a simulated trampling study and a similar effect likely contributed to higher runoff with increased grazing intensity in perennial treatments in our study. Increased bulk density with grazing intensity was measured in a concurrent study at this site (Twerdoff 1996). Naeth et al. (1990b) also measured increased bulk density with increased grazing intensity on Black Chernozems in Alberta. In our study, this effect may have been greater in perennials, which had not been cultivated for two years, than annuals, which were cultivated yearly.

Increased runoff with increased grazing intensity has been measured in several studies. Runoff generally increased with grazing intensity on Black Chernozems under foothills fescue grasslands (Naeth and Chanasyk 1996). Packer (1953) reported that as trampling disturbance on Idaho grasslands increased and ground cover was reduced, overland flow increased. Rauzi and Hanson (1966) reported that runoff increased with grazing intensity on South Dakota rangelands. Because of their permanent cover, perennial treatments in our study more closely resembled these grassland systems than annual treatments.

3.3.3 Total Sediment

All total sediment values were low and no clear trend with grazing intensity was measured (Table 3.3). Relative magnitudes among treatments for total snowmelt sediment were similar to those for total snowmelt runoff within years. Because overland flow, not raindrop impact or hoof action, resulted in sediment detachment and transport during snowmelt, sediment yield was likely volume-dependent. No significant differences were measured for total snowmelt sediment either year and values were generally less in 1994/95 than 1995/96.

Total rainfall sediment in 1994 was significantly greater for heavily grazed meadow bromegrass and barley/triticale than any other treatment. A

large proportion of high values was generated during the same intense rainfall event that produced high runoff in heavily grazed barley/triticale. Heavy runoff during this event in the barley/triticale treatment carried more sediment, while intense and frequent grazing of the meadow bromegrass treatment before the event enhanced sediment yield. No significant differences in total rainfall sediment were measured in 1995. Naeth and Chanasyk (1996) measured similarly low sediment yields on Black Chernozems under foothills fescue grasslands in Alberta and reported that rainfall sediment yield increased significantly under heavy and very heavy grazing compared to an ungrazed control. Johnston (1962), working in the same area, measured increased soil loss at very heavy grazing compared to light, moderate and heavy grazing under artificial rainfall. Differences in soil loss between light, moderate and heavy grazing intensities were minimal and sediment yields were within the same magnitude as those measured in our study.

All losses in our study were well below the 6 Mg ha^{-1} suggested by Tajek et al. (1985) as maximum tolerable soil loss on deep Chernozems in Alberta. Total snowmelt sediment yields were similar in magnitude to those measured by Chanansyk and Woytowich (1987) in the Peace River district of Alberta under fallow, barley, fescue and canola. Maximum losses of 2 Mg ha^{-1} were measured in canola and fallow. Our total rainfall sediment yields were slightly less than or similar to those measured by Toogood (1963) on Black Chernozemic silt loam soils near Edmonton, Alberta. In Toogood's study, rainfall sediment losses ranged from 0.1 Mg ha^{-1} to 0.5 Mg ha^{-1} under wheat, oats and barley. A maximum loss of 20.6 Mg ha^{-1} was measured on fallow. Plots were broken from virgin grassland, so organic matter levels were high in the soil surface horizon, contributing to aggregate stability and lowering runoff potential.

3.3.4 Average Sediment Concentration

No significant differences in average sediment concentration were measured among treatments during this study and all values were very low (Table 3.4). No clear trend with grazing intensity was measured in either year. Similarly, Naeth and Chanasyk (1996) found that snowmelt sediment concentrations did not differ across grazing intensities and that all values were low. They did, however, measure increased rainfall sediment concentration with increasing grazing intensity.

3.3.5 Average Runoff Coefficients

Average runoff coefficients were very low both years (Table 3.5). In 1994, the average runoff coefficient was significantly greater for heavily grazed barley/triticale than any other treatment and a significant (α=0.05) forage by grazing interaction was measured. For perennial treatments in 1995, average runoff coefficients were greater at heavy grazing intensity than any other treatment. No clear trend with grazing intensity was measured in annuals in 1995. Runoff coefficients measured by Naeth and Chanasyk (1996) were similarly low and increased with grazing intensity.

3.3.6 Benchmark Site

Total rainfall and snowmelt runoff for the benchmark site were within the same range as low to moderate values obtained for forage by grazing treatments in respective years (Table 3.6). Total snowmelt sediment for the benchmark site was within range of the smallest forage by grazing treatment totals each year. Total rainfall sediment yield and rainfall and snowmelt sediment concentrations were of low to intermediate size compared to forage by grazing treatment values for the same periods. These results indicate that average management practices within the Parkland ecoregion of Alberta, as represented by this reference benchmark site, may result in runoff and sediment levels not unlike those obtained in our study.

3.3.7 Correlations

A greater number of significant correlations between vegetation characteristics and runoff and sediment were measured in perennial treatments than annual treatments. (Table 3.7). Cultivation in annuals may have lead to increased soil surface roughness and decreased soil bulk density, and thus to increased infiltration, in annuals compared to perennials. Higher infiltration than in perennials may have resulted in poor correlations between vegetation characterisitics and runoff and sediment in annual treatments.

Fall litter was negatively correlated with rainfall sediment in smooth bromegrass (Table 3.7). Litter directly influenced rainfall runoff and sediment in a study by Simanton et al. (1991) on several different types of rangeland on a wide range of vegetation and soil types. A stronger correlation was measured in Simanton's study compared to ours, most likely because litter was measured at

time of runoff instead of the beginning and end of the growing season as in our study.

Total rainfall sediment was positively correlated with bare ground in meadow bromegrass but not smooth bromegrass (Table 3.7). Bare ground was greater in meadow bromegrass than smooth bromegrass at all grazing intensities both years, although not always significantly. It is not clear why rainfall runoff and sediment were negatively correlated with bare ground in the barley/triticale treatment.

No significant correlation between snowmelt runoff and sediment and spring litter was measured either year (data not shown). While standing litter increased snow trapping, and thus snowmelt runoff (Naeth and Chanasyk 1996) and sediment yield, surface litter slowed surface runoff and speed of melt, decreasing runoff and sediment (Chanasyk and Woytowich 1986). Standing and surface litter were not differentiated in this study and snow trapping by standing litter was not directly quantified, however, concurrent action of these two factors would likely minimize correlations and lead to observed results.

3.3.8 Management Considerations

Although our results were variable and in most cases no clear pattern emerged with grazing intensity, one result was clear: soil loss was not excessive in any case. The soil at this site is high in organic matter, well aggregated and has a high infiltration capacity. Ground cover, litter and post-grazing biomass protected the soil sufficiently from erosion at the grazing intensities implemented. At lower percent cover than measured in our study, soil losses might be considerably greater. Toogood (1963) measured a 20 Mg ha^{-1} total rainfall sediment yield and Chanasyk and Woytowich (1987) measured 2 Mg ha^{-1} total snowmelt sediment yield from fallow on Black Chernozems in Alberta. Because bare ground was generally greater in annuals than perennials in our study, annuals may be at greater risk to drop below threshold cover levels for soil protection. However, yearly cultivation of soil under heavily grazed annual pasture may improve infiltration compared to that in uncultivated soils under heavily grazed perennial pasture.

The pattern of increased total rainfall runoff with increased grazing intensity may become more pronounced in perennials over successive years of grazing and trampling. With increased runoff may come increased erosion, especially if trampling occurs on bare ground. Effects are difficult to predict, but

it seems wise to avoid very heavy grazing intensities on perennial forages because cumulative biomass removal and bulk density increase may increase total sediment yields to unacceptable levels.

In this study, runoff and sediment yield were assessed over a very short slope length, underestimating rill erosion potential (Goff et al. 1993). Chanasyk and Woytowich (1987) calculated that snowmelt sediment yields were 5.5 to 8 times greater on 75-m long slopes than on 22.1-m long slopes. No obvious rill erosion has been noted on our 31-m long plots over the two years of the study, however, rill erosion is possible if high snowmelt runoff occurred on slopes of sufficient length.

It appears that on this soil type under this hydrologic regime, the greatest risk of soil loss occurs during snowmelt and after major soil disturbance. Soil losses in this study were not excessive (maximum 0.23 Mg ha^{-1}) with post-grazing biomass levels as low as 0.5 Mg ha^{-1}.

3.4. Conclusions

1. All total runoff values were low and were higher for snowmelt than rainfall. Total rainfall runoff was highest in heavily grazed barley/triticale in 1994 and increased with increasing grazing intensity in perennials in 1995.
2. Total sediment yields and average sediment concentrations were low and no clear trend with grazing intensity was apparent. Total sediment yields were greatest in heavily grazed meadow bromegrass and barley/triticale in 1994.
3. Average runoff coefficients were low and increased with increasing grazing intensity in perennials in 1995.
4. A greater number of significant correlations between vegetation characteristics and runoff and sediment were measured in perennial treatments than annual treatments.

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Table 3.1. Total runoff for forage by grazing treatments, rainfall 1994 to snowmelt 1996.

	Runoff (Litres)			
	Snowmelt		Rainfall	
	1995	1996	1994	1995
Smooth Bromegrass				
Heavy	12.1	93.8	0.5 b	9.3 a
Medium	11.3	35.8	0.5 b	0.7 c
Light	29.7	171.9	0.2 b	0.2 c
Meadow Bromegrass				
Heavy	13.1	77.4	2.8 b	7.4 ab
Medium	16.2	149.3	0.6 b	2.0 bc
Light	8.8	57.9	0.3 b	0.1 c
Barley/Triticale				
Heavy	38.7	119.4	15.4 a	4.1 abc
Medium	3.4	50.4	3.0 b	3.1 abc
Light	36.0	113.5	0.2 b	3.3 abc
Triticale				
Heavy	20.6	101.5	0.4 b	0.3 c
Medium	4.2	30.7	3.3 b	4.5 abc
Light	8.5	145.9	0.2 b	0.1 c
SEM	17.2	40.3	1.5	2.0

Means within a column followed by the same letter are not significantly different at $p \leq 0.05$.
No differences in means within columns without letters were detected using Fisher's Protected LSD at $p \leq 0.05$.
SEM: Standard error of the forage by grazing means within a column.

Table 3.2. Percent of annual runoff during snowmelt for forage by grazing treatments, 1994 and 1995.

	Grazing Intensity			
	Heavy	Medium	Light	Year Mean
1994				
Smooth Bromegrass	94.7	99.2	98.7	
Meadow Bromegrass	96.9	99.5	99.3	97.4
Barley/Triticale	91.3	93.7	99.1	
Triticale	99.8	97.0	99.8	
1995				
Smooth Bromegrass	56.7	94.3	99.4	
Meadow Bromegrass	63.9	88.9	98.6	81.8
Barley/Triticale	90.5	52.1	91.6	
Triticale	98.5	48.4	99.0	
Two-Year Average	86.5	84.1	98.2	

Table 3.3. Total sediment yield for forage by grazing treatments, rainfall 1994 to snowmelt 1996.

	Total Sediment (kg ha^{-1})			
	Snowmelt		Rainfall	
	1995	1996	1994	1995
Smooth Bromegrass				
Heavy	6.9	69.2	2.2 b	55.4
Medium	0.6	12.0	0.1 b	6.0
Light	28.7	110.9	0.0 b	0.3
Meadow Bromegrass				
Heavy	1.4	9.5	132.4 a	185.3
Medium	9.7	63.6	0.2 b	16.2
Light	0.6	16.3	0.0 b	0.0
Barley/Triticale				
Heavy	10.9	114.9	178.2 a	69.6
Medium	0.5	26.4	7.5 b	224.5
Light	36.6	233.0	0.0 b	4.6
Triticale				
Heavy	29.0	192.8	0.0 b	4.0
Medium	0.5	33.9	13.9 b	66.3
Light	6.0	37.0	0.1 b	0.0
SEM	11.3	55.5	37.4	64.3

Means within a column followed by the same letter are not significantly different at $p \leq 0.05$.
No differences in means within columns without letters were detected using Fisher's Protected LSD at $p \leq 0.05$.
SEM: Standard error of the forage by grazing means within a column.

Table 3.4. Average snowmelt and rainfall sediment concentrations for forage by grazing treatments, rainfall 1994 to snowmelt 1996.

	Sediment Concentration (10^{-4} kg L^{-1})			
	Snowmelt		Rainfall	
	1995	1996	1994	1995
Smooth Bromegrass				
Heavy	0.65	0.66	2.91	6.22
Medium	0.03	0.32	0.08	4.72
Light	1.13	0.75	0.00	0.76
Meadow Bromegrass				
Heavy	0.05	0.10	34.61	49.24
Medium	0.78	0.44	0.33	4.49
Light	0.07	0.30	0.00	0.00
Barley/Triticale				
Heavy	0.27	0.91	13.54	10.49
Medium	0.11	0.50	2.39	52.25
Light	2.24	2.14	0.00	1.82
Triticale				
Heavy	0.70	1.75	0.00	6.80
Medium	0.06	1.04	3.38	16.56
Light	0.68	0.25	0.15	0.00
SEM	0.52	0.51	9.04	16.31

Means within a column followed by the same letter are not significantly different at $p \leq 0.05$.
No differences in means within columns without letters were detected using Fisher's Protected LSD at $p \leq 0.05$.
SEM: Standard error of the forage by grazing means within a column.

Table 3.5. Rainfall runoff coefficients for forage by grazing treatments, 1994 and 1995.

Runoff Coefficient (mm runoff mm^{-1} precipitation)	1994	1995
Smooth Bromegrass		
Heavy	0.0010 b	0.0361 a
Medium	0.0011 b	0.0022 c
Light	0.0005 b	0.0008 c
Meadow Bromegrass		
Heavy	0.0046 b	0.0330 ab
Medium	0.0013 b	0.0083 c
Light	0.0008 b	0.0005 c
Barley/Triticale		
Heavy	0.0274 a	0.0173 abc
Medium	0.0054 b	0.0108 bc
Light	0.0005 b	0.0133 abc
Triticale		
Heavy	0.0011 b	0.0010 c
Medium	0.0053 b	0.0171 abc
Light	0.0006 b	0.0004 c
SEM	0.0022	0.0006

Means within a column followed by the same letter are not significantly different at $p \leq 0.05$.
SEM: Standard error of the forage by grazing means within a column.

Table 3.6. Total runoff and sediment yield and average sediment concentration and rainfall runoff coefficients for benchmark site, snowmelt 1994 to snowmelt 1996.

	Total Runoff (Litres)	Total Sediment (kg ha^{-1})	Runoff Coefficient (mm runoff/mm ppt.)	Sediment Concentration (10^{-4} kg L^{-1})
Snow 1994	24.0	22.3		0.929
Snow 1995	43.8	0.0		0.000
Snow 1996	37.4	11.0		0.584
Rain 1994	3.2	2.7	0.005	0.551
Rain 1995	0.7	6.7	0.003	3.726

Table 3.7. Correlations (Pearson) between total rainfall runoff and sediment and vegetative characteristics across 1994 and 1995.

	Bare Ground	Early Season Post-grazing Biomass	Late Season Post-grazing Biomass	Leaf Area Index	Spring Litter	Fall Litter
Smooth Bromegrass						
Rainfall Runoff	NS	NS	NS	-0.66	NS	NS
Rainfall Sediment	NS	NS	NS	NS	NS	-0.56
Meadow Bromegrass						
Rainfall Runoff	NS	-0.59	NS	NS	NS	NS
Rainfall Sediment	0.70	NS	NS	NS	NS	NS
Barley/Triticale						
Rainfall Runoff	-0.80	NS	NS	NS	NS	NS
Rainfall Sediment	-0.85	NS	NS	NS	NS	NS
Triticale						
Rainfall Runoff	NS	NS	NS	NS	NS	NS
Rainfall Sediment	NS	NS	NS	NS	NS	NS

Values greater than or equal to 0.55 are significant at $p \leq 0.05$.
NS = not significant.

CHAPTER 4

SYNTHESIS

4.1 Controlled Versus Uncontrolled Studies

This study provided me with a better understanding of why researchers make the choices they do when designing and conducting experiments. Experimental factors can be controlled by mowing rather than grazing or by introducing artificial precipitation rather than waiting for rain to fall. Variability can thus be minimized and one generally can control range of measurement. Many of the statistical pitfalls inherent in non-homogeneous variance, non-normal datasets and large numbers of zero values are avoided. However, with a controlled study, reality is somewhat altered and one may unwittingly modify the way factors interact. In contrast, I had to wait for rainfall events, cope with uneven grazing and struggle with messy statistics. However, I was, in the end, glad I opted to assess runoff, sediment and vegetation characteristics using a non-controlled approach because I was able to observe the unhampered interconnectedness of a grazing system.

4.2 The Grazing System

Soil, vegetation, weather and animals interacted in this study to determine runoff and erosion. Because all these system components were operating concurrently, the challenge became determining what soil, vegetation, grazing and meteorological parameters most influenced results.

Each forage type differed in its ability to prevent runoff and erosion because of differences in amount and arrangement of litter and ground cover and response to grazing. Vegetation directly and indirectly protected against soil erosion through addition of organic material and protection of the soil surface from raindrop impact and overland flow. Because of its potentially extensive contact with the soil surface and its persistence throughout the year, litter was an important factor in minimizing runoff and erosion.

The cattle component of the system created soil disturbance and compaction and removed vegetation, increasing runoff and erosion potential. The breakdown of litter was accelerated under cattle trampling, further decreasing erosion protection. At the same time, cattle provided inputs of

manure and urine, which increased fertility, decreased palatability of certain portions of the sward and provided ground cover.

The meteorological component of the system influenced soil conditions and governed timing and intensity of precipitation. Intense rainfall events and large snowmelt events increased the potential for runoff and erosion. Freezing temperatures increased the likelihood of frozen ground and limited infiltration. High temperatures increased evaporation from soil and transpiration from vegetation, lowering soil water and increasing infiltration potential.

4.3 Vegetation Characteristics, Grazing Intensity and Runoff and Erosion

Our hypothesis that runoff and sediment would be highest in barley/triticale, followed by triticale, meadow bromegrass and smooth bromegrass was not strongly supported by our results. Rainfall and snowmelt runoff and erosion were not consistently higher in annuals than perennials, even though bare ground was much greater. Only in perennials in the second year of the study did rainfall runoff and runoff coefficients increase with increased grazing intensity. Litter seemed to be increasing from year to year in perennials compared to annuals, especially at light grazing, although this was not tested statistically. Management differences between annuals and perennials are the most likely reason that this occurred. Whereas grazing affects only one year's growth in annuals, grazing effects in perennials are cumulative across years. If this study were to continue for several more years, differences in vegetation characteristics and runoff and erosion between annuals and perennials and between grazing intensities within perennials would probably become more pronounced. Litter might build up at lower grazing intensities in perennials, increasing soil surface roughness and water holding capacity, while bare ground, compaction and runoff might increase under heavy grazing. Differences in cover, litter and compaction would most likely be much greater between heavily and lightly grazed perennials than annuals after several years.

There were no obvious relationships between sediment yield or sediment concentration and measured vegetation characteristics. Because soil structure appears excellent and infiltration rates appear high at this site, the amounts of litter, ground cover and live biomass produced by all treatments

seem sufficient to minimize sediment yield. Sediment yields were highest each year in the heavily and medium grazed barley/triticale and meadow bromegrass treatments, perhaps because of sward structure in these species. Meadow bromegrass has a weaker creeping habit than smooth bromegrass, so there were probably larger gaps in the sward. Barley died out of the sward with grazing and grew in an erect manner, so more there were more spaces than in triticale. Size of bare ground openings between litter and live cover was found to influence runoff and erosion in a study by Packer (1953) on wheatgrass and cheatgrass ranges and a similar effect may be occurring here.

4.4 Future Research

Research is warranted to provide clarification of, and explore further, certain relationships. The relationship between slope length and runoff and erosion could be examined in greater detail. Would a longer slope length result in rill erosion, especially during snowmelt? Perhaps several of our research plots could be entirely enclosed so that they essentially became very large runoff frames. A heavy grazing intensity could be implemented and runoff and sediment collected from each entire plot. The relationship between runoff and erosion and grazing intensity could be examined more closely. Do runoff and sediment increase linearly with grazing intensity? I suspect not, as runoff and sediment and vegetative characteristics were more similar between medium and lightly grazed treatments than heavily grazed treatments. Similar studies conducted on different soil types in Alberta, especially those that crust easily, could provide comparative information on runoff and erosion.

Questions which lead to related studies are generated by our results. How does yearly cultivation affect soil characteristics which influence runoff? Are differences in these characteristics going to increase with time between annuals and perennials? Will compaction in perennials increase with time under heavy grazing? To what degree does water use by vegetation affect runoff? Some of these questions are currently being addressed by other researchers. I eagerly await their results!

4.5 Literature Cited

Packer, P.E. 1953. Effects of trampling disturbance on watershed condition, runoff and erosion. J. Forestry 51:28-31.

APPENDIX A

Plot **Rep** **Treat.** **Forage** **Grazing**	12 1 12 triticale light	11 1 10 triticale heavy	10 1 3 s.brome light	9 1 6 m.brome light	8 1 2 s.brome medium	7 1 11 triticale medium	6 1 7 barly/trit heavy	5 1 1 s.brome heavy	4 1 8 barly/trit medium	3 1 5 m.brome medium	2 1 4 m.brome heavy	1 1 9 barly/trit light
Plot **Rep** **Treat.** **Forage** **Grazing**	24 2 7 barly/trit. heavy	23 2 4 m.brome heavy	22 2 11 triticale medium	21 2 8 barly/trit medium	20 2 9 barly/trit light	19 2 10 triticale heavy	18 2 5 m.brome medium	17 2 12 triticale light	16 2 3 s.brome light	15 2 6 m.brome light	14 2 1 s.brome heavy	13 2 2 s.brome medium
Plot **Rep** **Treat.** **Forage** **Grazing**	36 3 9 barly/trit light	35 3 12 triticale light	34 3 2 s. brome medium	33 3 1 s.brome heavy	32 3 7 barly/trit heavy	31 3 3 s.brome light	30 3 4 m.brome heavy	29 3 8 barly/trit medium	28 33 11 triticale medium	27 3 10 triticale heavy	26 3 6 m.brome light	25 3 5 m.brome medium
Plot **Rep** **Treat.** **Forage** **Grazing**	48 4 1 s.brome heavy	47 4 8 barly/trit medium	46 4 5 m.brome medium	45 4 4 m.brome heavy	44 4 6 m.brome light	43 4 9 barly/trit light	42 4 3 s.brome light	41 4 7 barly/trit heavy	40 4 10 triticale heavy	39 4 12 triticale light	38 4 2 s. brome medium (missing)	37 4 11 triticale medium

Figure 1. Overview of experimental design.

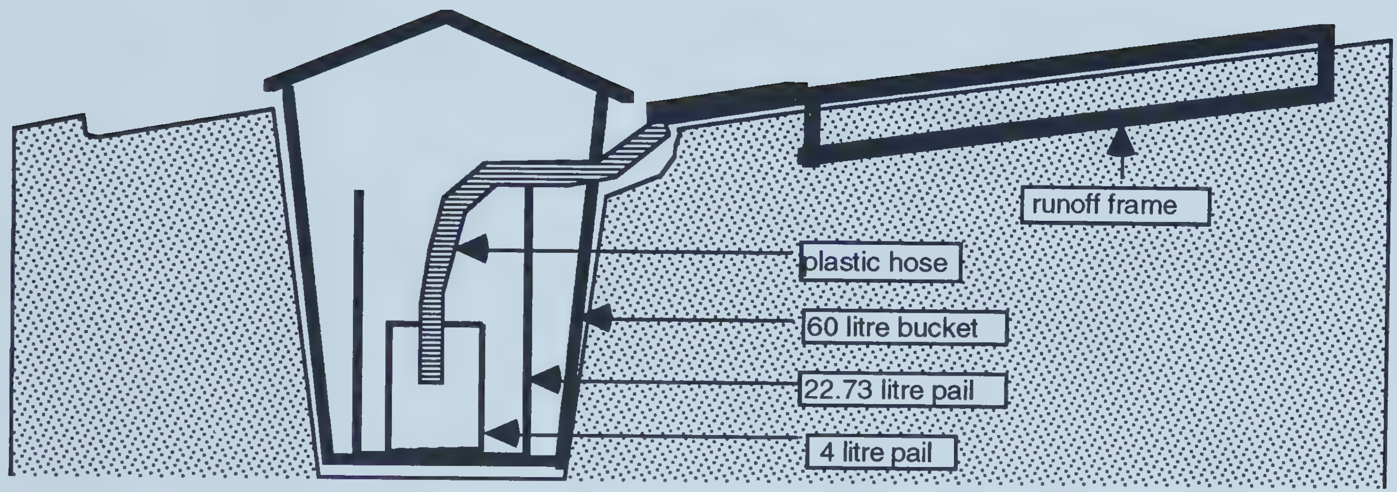

Figure 2. Crossection Of Runoff Frame Assembly.

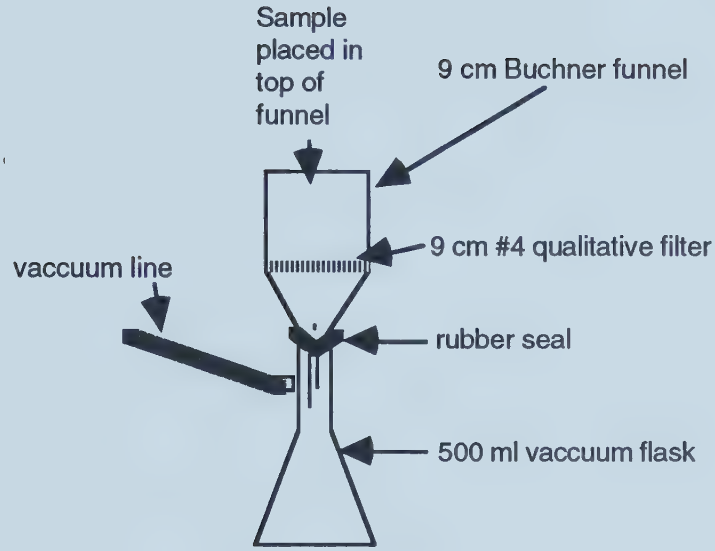

Figure 3. Buchner funnel and vaccuum flask arrangement for filtering runoff samples.